THE ACOUSTIC PERFORMANCE OF NOVEL NOISE BARRIER PROFILES MEASURED AT THE ROADSIDE

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As part of continuing investigation into noise barrier optimisation, a research and development study to conduct insitu empirical testing of several full size prototype barrier designs was funded by the NSW State Government. Of particular interest to this study was a design known as a random edge profile barrier. Literature research had found that there was a body of evidence indicating that a barrier with an edge irregularity can cause a substantial degradation of the diffracted signal. It is generally accepted that an increase in insertion loss occurs because the jagged edge causes a reduction in coherence of the diffracted signal being transmitted to the shadow zone as compared to a conventional straight edge barrier [1-3]. It has been suggested that the mechanism for this is that the jagged geometry on the top of a barrier alters the sound pressure level in the shadow zone by causing the region of the barrier nearest the receiver to admit multiple paths with variable phase [4]. The direct waves from the diffracting edges of the barrier and waves subsequently reflected from the ground plane are superimposed at the receiver causing constructive or destructive interference at the receiver. The present study followed a methodology that included construction of an 80m long by 2.4m high barrier that served as the base for an additional conventional top as well as a random profile and T-top novel cap. Empirical data collected showed that for the receiver locations investigated, a random edge barrier will out-perform a conventional barrier of the same nominal height for most frequencies associated with broadband tyre/road noise. A T-top barrier was found to perform better than a conventional barrier of similar height for most frequencies whilst a conventional barrier offered the most practical solution for attenuation of low frequency noise.

INTRODUCTION

In reviewing developments in the design, construction and performance of roadside noise barriers, researchers found that barriers with novel cappings appeared to be capable of providing considerable increases in attenuation, particularly in the higher acoustic frequency regions [5, 6]. The implications of these findings were twofold.

- Capped barriers of the same height as conventional barriers could potentially provide greater noise reductions than the conventional barriers.
- A specified noise reduction could potentially be provided by a capped barrier of lower height than a conventional barrier.

In NSW, barrier designs that do not deliver at least a 10 dB(A) reduction are generally not considered economically viable. Therefore, the potential benefits were considered sufficient enough to warrant further investigation and a research and development study to conduct in situ empirical testing of several full size prototype barrier designs was subsequently funded.

Of particular interest to this study was a design known as a random edge profile (or jagged edge) barrier such as that presented in Figure 1. The available evidence was that a barrier with such an edge irregularity can produce increased insertion loss because the jagged edge causes a reduction in coherence of the diffracted signal being transmitted to the shadow zone compared to a conventional straight edge barrier [3].

Figure 1: Representation of a random edge barrier used in the study

Researchers have reported enhanced performance for random edge barriers at higher frequencies but reduced performance at lower frequencies [1, 7]. In particular, it has been indicated the cross over point in performance occurs around 2000–5000 Hz [2, 3]. This suggested that whilst there would be some benefits to reducing broadband road traffic noise, the critical areas of maximum acoustic energy which lie below 2000 Hz would not experience any improvement. Moreover, in most cases there would be degradation in performance as compared to a conventional straight edge barrier in this frequency range. Studies such as those cited above also indicated that these types of jagged edge barriers tend to perform better when the noise source is closer to the barrier. However, these studies were mostly conducted on small scale models or by using the boundary element method and the authors have been unable to find any reports of full scale testing of random edge profile barriers under normal traffic conditions.

THE EMPIRICAL STUDY

The Study Set-up

The objective of the empirical study reported in the present paper was to undertake a full scale experiment to determine the insertion loss of a random edge barrier and to compare these results with those of conventional straight edge barriers and with that of a barrier with a T-top configuration. A conventional 2.4m high barrier was constructed at the study site and was subsequently fitted with a T-top which maintained the height but added 0.6m horizontally to each side. The T-top was later removed and the conventional barrier was then increased in height to 3.0m, from which the upper 0.6m was later replaced with a random edge top as shown in Figure 1. Thus the performance of four barriers were investigated in the study.

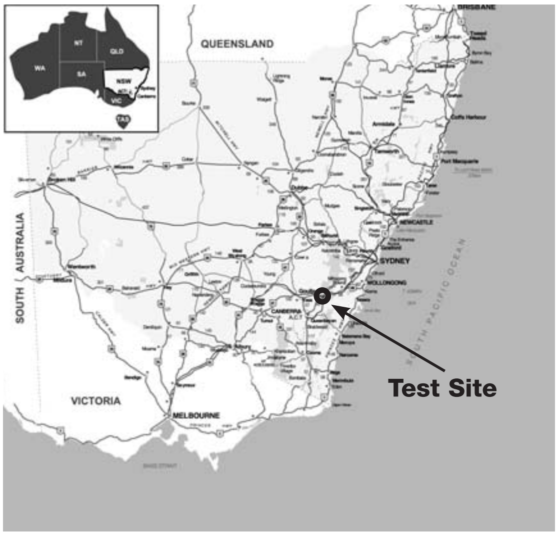

Figure 2: Location of test site

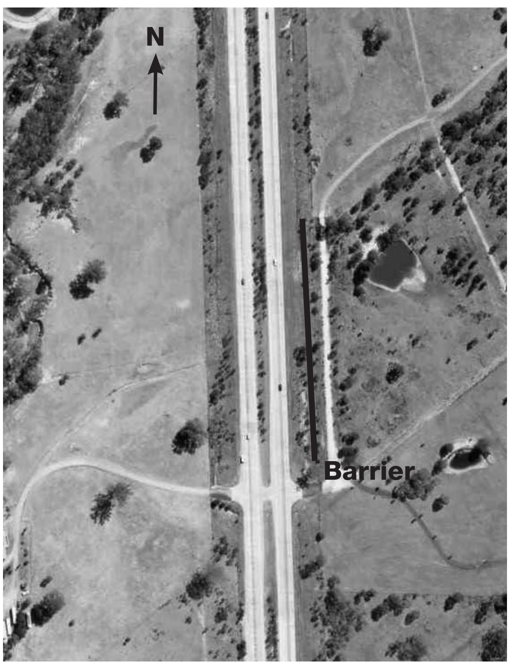

Figure 3: Barrier location

The study site was located on a section of the Hume Highway in NSW between Marulan and Goulburn. The barriers were constructed of a 28 mm timber laminate developed exclusively for use as a noise barrier. This laminate was provided in sheets that were 2.4 x 1.2m and were fixed between galvanized H beams. The barriers are shown in Photos 1 - 4. The various extensions and tops were also constructed of the 28 mm laminate and any gaps were suitably filled to eliminate any leakage. Researchers [8] have quantified the reduction of insertion loss resulting from air gaps in less substantial timber noise barriers, however in the case of this barrier, the authors have confidence that there was no potential for any leakage. As finally constructed, the barrier was 80m long with an average setback of 22.3m from the south bound carriageway of the Hume Highway. CoRTN algorithms [9] indicate that to prevent contributing leakage around barrier requires the barrier to subtend an angle of around 160° to the road. To comply with this therefore restricted measurements to no more than 7m behind the barrier. Whilst it would have been preferable to obtain measurements at distances further behind the barrier, this would have required a much longer barrier which was not an option within the study budget.

Photo 1. Section of highway (from Gipsicam)

Photo 2. Conventional barrier (2.4m)

Photo 3. T-top barrier (2.4m)

Photo 4. Random edge barrier (3.0m)

Data Collection and Analysis

Three precision (Type 1) microphones were set up at various locations in front of, and behind each barrier configuration (including the no barrier scenario). Designated A, B, and C these microphones captured traffic noise data simultaneously at various combinations of the measurement points shown in Figure 4 and listed in Table 1. Extensive sets of data were collected for each barrier configuration and were also duplicated in the absence of any barrier. A 01dB Metravib Harmonie four channel analyser capable of collecting data from three microphones simultaneously at a sampling rate of 51.2 kHz was used to collect and analyse the road traffic noise data. Synchronised video footage of the roadway was also collected to allow identification and characterisation where necessary. The analyses involved determining noise indices such as the Leq and producing various frequency spectra of the traffic noise signals.

An assessment of potential barrier reflection to measurement point 1(MP1) did not indicate it would be a significant feature of the experiment. This conclusion was supported by the 'no barrier' measurements and as a result, barrier reflection was not considered further.

Figure 4: Cross section showing microphone positions A, B & C and barrier position

Table 1: Measurement points

Position	Measurement Point	In front or behind barrier	Location of measurement point relative to base of barrier	
			Height (m)	Distance from barrier (m)
At the barrier Microphones A,B & C	1	Front	1.2	2.4
	2	Behind	1.2	2.4
	3	Behind	1.2	4.8
	4	Behind	1.8	2.4
	5	Behind	1.8	4.8

As indicated in Table 1, there was a substantial set of data collected during the course of the investigation and subsequently a vast range of results ensued. Only the key results are summarised in the present paper. Firstly, the measured traffic noise Leq levels at the five measurement points, averaged over replicate samples at each measurement point, are set out in Table 2. Because road traffic is not a controllable steady noise source it is normally difficult to compare one monitoring period against another (although this site provided extremely reproducible conditions). However, use of a carefully configured experimental design involving sequential, simultaneous monitoring at various combinations of the four shielded measurement points ensured that the data of Table 2 could all validly be compared against one another and presented in Table 3 [9].

Importantly, this experimental design also ensured that the data differential in Table 3 were, in effect, independent of the influences of factors such as fluctuations in the traffic volume, composition and speed during the measurements.

Table 2: Average traffic noise levels at the 5 measurement points

Barrier Type	Averaged L_{eq} Traffic Noise Level (dB(A))				
	MP1	MP2	MP3	MP4	MP5
Conventional 2.4m	75.4	63.1	63.1	64.1	64.5
Conventional 3.0m	75.9	60.9	61.5	61.8	62.9
T-top	76.3	62.1	62.6	64.3	65.7
Random edge	75.6	60.9	60.4	62.1	61.1
No barrier	75.5	71.7	69.8	73.1	71.3

Table 3: Average measured attenuations

Barrier Type	Averaged attenuation between MP 1 and MPs 2 to 5 L_{eq} dB(A)			
	MP 2 (std dev)	MP 3 (std dev)	MP 4 (std dev)	MP 5 (std dev)
Conventional 2.4m*	12.8 (0.34)	12.5 (0.39)	11.3 (0.38)	11.0 (0.44)
Conventional 3.0m*	15.0 (0.06)	14.4 (0.06)	14.0 (0.29)	12.9 (0.25)
T-top*	13.9 (0.21)	13.2 (0.21)	12.2 (0.19)	10.7 (0.28)
Random edge*	14.7 (0.11)	15.2 (0.21)	13.5 (0.19)	14.4 (0.39)
No barrier*	3.2	5.0	1.5	3.3
TNM predicted	1.6	2.0	1.4	2.0

* 2.5kHz band pass filtered

Observations

In the initial reporting of this study [10, 11], offsets for the distance attenuation between MP1 and the 'behind barrier' positions MP2 to MP5 were estimated using the US FHWA traffic noise prediction model TNM. Measurements made following the removal of the barrier have shown that actual distance attenuation for this study site to be much higher than expected, most likely as a result of ground impedance effects. These effects can be difficult to quantify [12, 13] and whilst these findings warrant further investigation, the effects over such short distances are generally restricted to the less important higher frequency bands and are outside the scope of the current study. Based on confidence in the scientific method used, the high signal to noise ratio, appropriate study area and the good repeatability of measurement, anomalies with higher frequency data have been addressed by band pass filtering the signal to 2.5 kHz which is consistent with other researchers who have chosen to limit their data to similar upper frequencies [14, 15].

Whilst ground effects behind the barrier would be important in quantifying site specific absolute levels of insertion loss, the objective of the study was rather to compare the performance of the various barrier types. Therefore to eliminate uncertainty associated with determination of absolute levels of barrier insertion loss and the need to account for the variation in distance setbacks between the measurement points, this paper presents the performance of the trial barriers relative to the performance of the conventional 2.4m barrier.

Review and Re-Presentation of Data

Some data collected as part of this study has previously been presented [10, 11, 16, 17] and the authors have benefited from reviews, comments and requests for additional details. The authors are thankful for this feedback and have refined the presentation of data in this latest paper in line with comments received. Notable improvements to the presentation of data include: removal of frequency data (>2.5 kHz) which were outside the range of frequencies of interest and which tended to introduce higher sample variance without improving understanding of the mechanisms under investigation; provision of some statistical assessment of the reported results; use of the conventional 2.4m barrier as reference for assessing the performance of the other test barriers.

SUMMARY OF THE KEY OUTCOMES ACROSS THE FREQUENCY SPECTRA

Typical outcomes of the study across the frequency spectra have been reproduced in Figures 5 and 6 which show relative attenuation of the test barriers at MP2 and MP5. Before interpreting what appears in these figures it should be noted that road traffic noise is relatively broadband in nature and that the majority of acoustic energy, which is generated by tyre/road interaction, lies in the 250 Hz to 4 kHz range and sometimes down to 50 Hz [18, 19]. The Portland cement concrete pavement in place at the study site tended to exhibit more discrete frequencies than some other types of pavements such as dense graded asphalt, however it provided traffic noise levels with an excellent signal to noise ratio for the measurements of the study. Table 4 presents the performance of the conventional 3.0m, T-top and random edge barriers relative to the performance of the conventional 2.4m barrier at the various receiver points behind the barrier.

Table 4: Attenuation performance relative to conventional 2.4m barrier

Barrier Type	Change in attenuation relative to conventional 2.4m barrier L_{eq} dB(A)				Average Change
	MP 2	MP 3	MP 4	MP 5	
Conventional 3.0m*	2.2	1.9	2.6	1.9	10.8
T-top*	1.1	0.7	0.9	-0.3	9.3
Random edge*	1.9	2.7	2.2	3.4	11.2

* 2.5kHz band pass filtered

It is apparent in Table 4 that relative to the reference barrier, the conventional 3.0m and T–top barriers were found to perform better at MP 2 (setback 2.4m, height 1.2m) and MP 4 (setback 2.4m, height 1.8m) than they do at further distances from the barrier. Conversely the relative performance of the random edge barrier was seen to increase in comparisons of less shielded positions, either at greater setbacks or more elevated positions. At the least shielded position MP5 (setback 4.8m, height 1.8m) the random edge barrier was found to out-perform the conventional 2.4m barrier by 3.4 dB(A) and the conventional 3.0m barrier by 1.5 dB(A). This result indicates destructive interference mechanisms are occurring, particularly where angles of diffraction are low. In retrospect, it would have been valuable to have undertaken more detailed measurements in shadow zone to determine if the improved attenuation is a result of when the signal grazes over the barrier edge and diffraction angles are low or if it is related to an optimised reflection behind the barrier.

Whilst the T-top barrier shows performance improvements over the conventional 2.4m barrier at points in close proximity to the barrier, it shows little or no advantage at the more exposed receiver points. At MP 5 the T-top barrier was found to perform slightly worse overall (0.3 dB(A)) than the conventional 2.4m barrier, however this result is within the margins of error.

Earlier analysis of the T-top barrier [10, 11] concluded that this barrier performed better at higher frequencies. Band pass filtering the data to <2.5kHz has reduced this advantage and indicates little benefit for receivers not in close proximity to the barrier. This conclusion may however be different if the T-top was larger or the barrier was close enough to the road that the T-top overhung the road.

The low performance of T-top barrier in the low and mid frequencies at this study site may be one reason other researchers are sometimes able to report they are able to gain significant improvements by the addition of absorptive material, quadratic residue diffusers and primitive root diffusers [20, 21]. At sites where T-top barriers are reported to be performing well, the addition of these covers appears to perform below expectations [22].

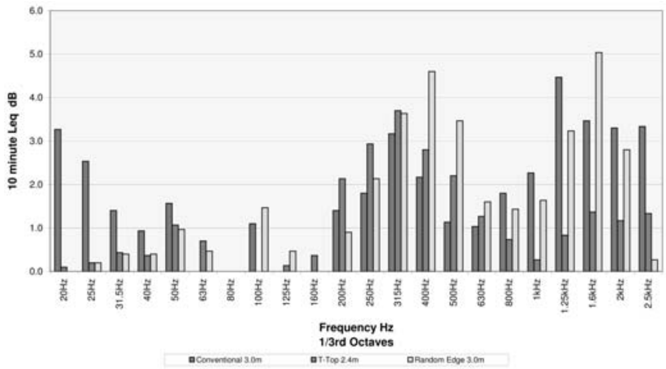

Figure 5: Comparison of spectral data of test barriers to the conventional 2.4m reference barrier at MP2

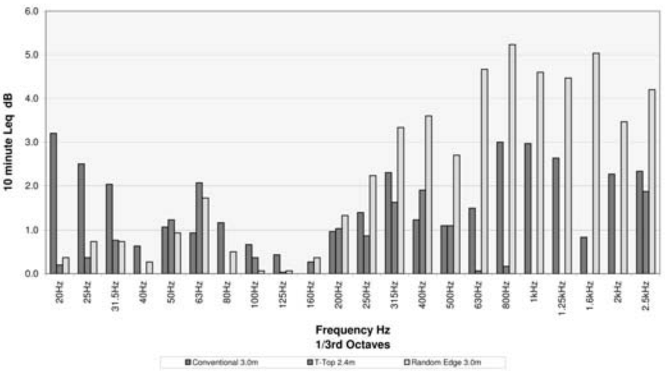

Figure 6: Comparison of spectral data of test barriers to the conventional 2.4m reference barrier at MP5

These results, along with those from the various other measurement points, appear to be consistent with theoretical evidence that the random edge disrupts the coherence of the acoustic waves as they are diffracted by the barrier edge. This conclusion was also supported by the observations that the greatest differential improvement in insertion loss occurred at those locations close to the shadow/bright zone interfaces (MP 3 and 5).

Future Areas of Research

Comments have been received regarding the use of absorptive material and devices on the barrier surfaces. Investigation of improvements resulting from these surface modifications is worthy of study of its own however these options were discounted as this study focused on barrier types that had a realistic chance of being incorporated into highway projects. The literature contains a plethora of acoustically interesting barrier designs, however it is highly unlikely that absorptive type of barriers would ever be built because of urban design, maintenance and cost considerations. Furthermore studies have shown actual performance is often much less than predicted.

One area worthy of further research is to quantify the extent of the zone of destructive interference behind the random edge barrier. It is unknown whether the benefits indentified in this study would extend indefinitely or are optimised at some set distance.

CONCLUSIONS

Overall, the following conclusions ensued from the study and are reported in the present paper.

- The overall acoustical performances of the conventional noise barriers used in this study, which was limited to receivers being no further than 4.8m behind the barriers, were improved by introducing the novel barrier cappings.
- The random edge barrier was found to out-perform the other noise barriers tested in this study over the frequencies that generally make up broadband road traffic noise. In close proximity to the barrier and from 160 Hz to around 630 Hz the T-top barrier was able to out-perform both conventional barriers, thereafter it continued to out-perform the conventional 2.4m barrier. For the lower frequencies below around 50 Hz, the conventional 3.0m barrier was found to afford superior attenuation. Low frequency noise can be generated by heavy vehicle engine compression brakes, therefore there may be no real advantage in utilising novel barrier tops in an attempt to address this particular issue.
- Earlier investigations reported in the literature had suggested that the crossover point for performance improvement between conventional barriers and random edge barriers typically occurred somewhere between 2 kHz and 5kHz [2, 3]. The conclusion of the present study is, however, that this crossover point is closer to 250 Hz for the barriers investigated. The implication of this finding is that random edge barriers of the type studied may provide significant improvements in attenuating road traffic noise within the critical frequency bands of maximum acoustic energy.
- Care must be taken in reporting absolute values for insertion loss for noise barriers as site specific variables can significantly influence the attenuation measured, particularly if assumptions are being made regarding the 'no barrier' scenario.
- The random edge barrier provides significant advantage over the other designs for the less shielded receiver locations behind the barrier, however it is unknown how far the area of influence extends.

ACKNOWLEDGEMENTS

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